Conference Paper, Published Version

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Laboratory Simulation, The Best Method To Critical Granular Filter Design

LABORATORY SIMULATION,
THE BEST METHOD TO CRITICAL GRANULAR FILTER DESIGN

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Critical filter with a simple but effective job is one of the principal parts of an embankment dam which is able to immune the dam against erosion, prevent water escape and seal unfavorable cracks that may occur through the impermeable core. This paper covers almost all of the effective factors that influence the behavior and correspondingly the design of filter that are presented in the literature. According to these factors and some experimental comparisons, it is shown how laboratory simulation could be the best method to critical granular filter design.

1 Introduction

Filter is a principal part in an embankment dam. This importance is because of the critical job of filter to protect the core (often clay) against erosion. A proper filter is also able to control and seal unfavorable cracks that may occur through the impermeable core. Terzaghi [1925] was the first one who works on filters. He proposed criteria for designing filters. Another important event dates back to 1989 when Sherard et al. finished their research on filter. They proposed a laboratory test called NEF to control the behavior of a filter-soil system. Today, some other features like analytical and numerical studies are followed by experts.

Among all of the methods, laboratory simulation such as NEF seems still to be the best way of designing. To explain the reasons, this study has reviewed the literature. It was found that many factors like gradation curve and its properties, relative density of filter, grain shape, hydraulic gradient, physico-chemical properties, fine content, filter thickness, internal stability, problematic soils, etc. affect the soil-filter behavior. Later in this paper these factors are explained. The study, supported by some experimental comparisons, shows how a laboratory simulation is the best method to critical granular filter design.

2 Proper Filters[a]

To function correctly, filters must be:

[a] Exactly from Loke et al. [2000]

(1) Fine enough that the pores between the filter particles are sufficiently small to hold some of the larger particles of the protected materials in place (the retention criterion).
(2) Coarse enough to allow seepage flow to pass through the filter, preventing build up of high pore pressures and hydraulic gradients (the permeability criterion).
(3) Non cohesive - fine particles within the filter material should be limited so that the filter is cohesionless and no cavities or cracks can be sustained within the filter (the no-cohesion criterion).

3 Laboratory Simulation Methods

3.1 NEF (No Erosion Filter) Test

Sherard et al [1989] proposed a new test called NEF which was repeatable and powerful in assessing a soil-filter system. He proposed this test to design the critical granular filters. Critical filters are those that are used at downstream of the core in an embankment dam. Fig. 1 shows the schematic shape and size of the test apparatus. In this test, the hole represents a crack in the core.

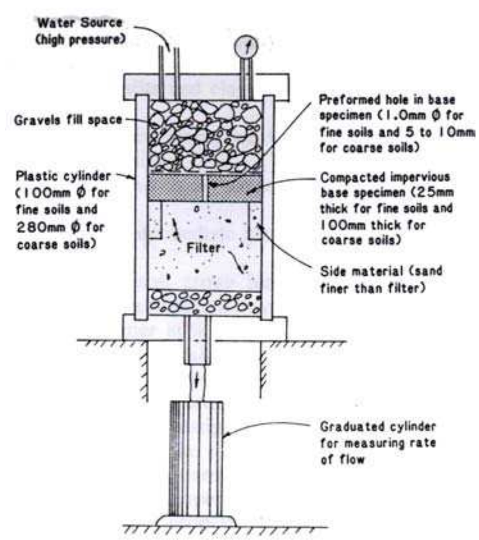

Figure 1. NEF test apparatus.

The water darkness, the outlet discharge and the diameter of the hole after the test show whether the filter is successful and can seal the crack or not. He carried out this test for a vast set of soils and finally proposed his criteria as presented in Table 1.

Table 1. Sherard Criteria for Critical granular filters

Base Soil Group	**Fine Content by sieve No. 200 %**	**Criteria**
1	85-100	$D_{15F} \leq 9D_{85B}$
2	40-80	$D_{15F} \leq 0.7_{mm}$
3	0-15	$D_{15F} \leq 4D_{85B}$
4	15-40	Intermediate between group 2 & 3

3.2 CEF (Continuing Erosion Filter) Test

The other test that has been proposed these days is CEF. For the fist time this test which is too similar to NEF has been carried out to assess the long term behavior of a soil-filter system by Foster and Fell [1999] during a study on some old dams in Australia.

Foster and Fell [1999] showed that for any soil-filter system there is another limit (rather than no-erosion limit) before which the erosion will be finally finished. However exceeding this limit, the filter cannot control the erosion even after a long period of time. CEF has been shown in Fig. 2.

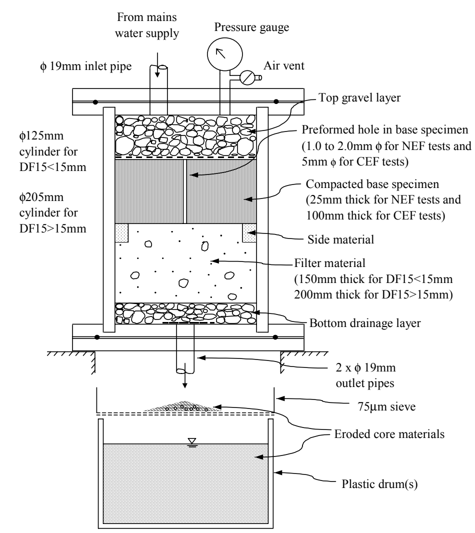

Figure 2 continuing erosion filter test apparatus.

4 Results of the Laboratory Tests

In a study to design filters for three dams in Iran, eight sets of NEF tests were carried out. To have a good comparison, all of the tests were carried out in the same way that has been proposed by Sherard et al. [1989]. Results showed that although the Sherard criteria come from the NEF test, they are not the suitable ways to find the best and optimum filter. This has been already accepted by Sherard. Table 2 represents these test results. As it is understood from the table, there is no good agreement between results and criteria. More details are available by direct contact to the authors.

Table 2. Comparison between NEF test results and Criteria

Test no.	Base Soil group	Criterion	Required Parameters		Criteria Satisfactory	NEF Test Results	Compatibility of Tests & Criteria
			D_{15F} mm	**D_{85B}** mm			
1	1	$D_{15F} \leq 9D_{85B}$	0.25	0.04	Yes	Successful	No
2	1	$D_{15F} \leq 9D_{85B}$	0.37	0.04	Yes	Unsuccessful	No
3	1	$D_{15F} \leq 9D_{85B}$	0.35	0.026	No	Semi-Successful	-
4	1	$D_{15F} \leq 9D_{85B}$	0.1	0.026	Yes	Semi-Successful	-
5	2	$D_{15F} < 0.7_{mm}$	0.4	-	Yes	Successful	Yes
6	1	$D_{15F} \leq 9D_{85B}$	0.4	0.075	Yes	Successful	Yes
7	1	$D_{15F} \leq 9D_{85B}$	0.6	0.03	No	Successful	No
8	2	$D_{15F} < 0.7_{mm}$	0.35	-	Yes	Unsuccessful	No

5 Effective Parameters on a Soil-Filter System

To assess the differences and similarities between laboratory tests and criteria, a complete literature review was done. It showed that there are many factors affecting the soil-filter system behavior. Here, some of these parameters are presented:

5.1 Gradation Curve and relevant Parameters

Gradation curve is the first step to evaluate the primary behavior of soils. This curve can determine some of the physical and engineering properties of soil. It is clear that to reach the first functioning of filter (retention), filter curve should be on the right side of the base soil curve (Fig. 3).

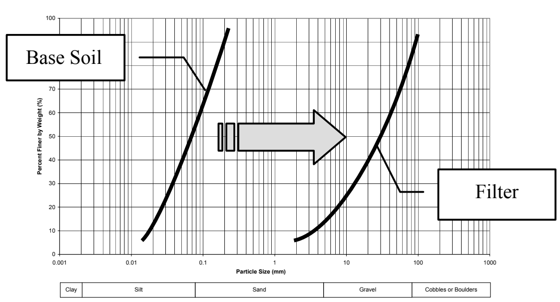

Figure 3 location of base soil and filter curves.

Shape, width, uniformity and broadly grading are the relevant parameters change the functioning of a soil-filter system (Laufleur and Mlynarek, 1989). Nevertheless, all of these parameters are expressed in the criteria just by some simple terms like D_x (:particle size for which x % by weight of particles are smaller) or relations like:

$$D_{xf} / D_{yb} < \alpha \tag{1}$$

where f and b stand for filter and base soil respectively and α is constant. These relations cannot simulate the real condition. On the other hand, the acceptance of parallelism of filter and soil curves is another challengeable issue, e.g. Sherard et al. [1989] and Honjo and Veneziano [1989] have two opposite ideas.

5.2 Permeability

The second functioning of a proper filter is satisfied when:

$$K_{filter} / K_{soil} > \beta \tag{2}$$

where K is the hydraulic conductivity coefficient of filter and base soil and β is constant. Although K is a function of many effective parameters, especially in fine soils, such as porosity and soil fiber, it is expressed by simple terms. Kenney et al. [1985] showed that K is related to D_α^2, but he proposed α just for his tested soils. Other researchers have proposed in a similar way such as D_{15} by Terzaghi [1925] and D_5, D_{10} by Indraratna and Vafai [1997]. Some other studies, e.g. Vaughn and Soares [1982] related K to the chemical properties of fluid and soil.

5.3 Fine Content of the Filter

Fine content by sieve #200 (75μm) directly affects the cohesion properties of filter. The more the fine content, the more the cracking potential in the filter.

Foster and Fell [1999] proposed that fine content should be under 5% to be sure that there is no cracking potential in the filter. If fine content exceeds 15%, filter won't control the erosion and for the gap between 5% and 15% more studies are needed.

5.4 Filter Particle Shape

It is clear that the particle shape affects the distribution of pores between particles in the filter. The more the particle shape similarity, the more the space between them. Thereby, the different particle shapes can cause a denser filter.

Bertram [1940] was the first one who studied this issue. He and others after him found that a non similar particle shape filter is more effective than the similar shape one.

5.5 Relative density

Relative Density (D_r %) is one of the important parameters for the granular soils. This parameter divides soils into two groups; dense and loose. Almost all of the studies have proposed to use a dense filter instead of the loose one. However they do not suggest any certain limit to distinguish these two. Sherard et al. [1989] used D_r between 80 to 100%. But these limits or any other one cannot guarantee the successful behavior of filter.

Jahanandish and Abolghasempoor [2003] showed that there is an especial value of D_r below which filters cannot control the erosion. They suggest more studies for determining this critical D_r.

5.6 Hydraulic Gradient

Hydraulic gradient represents the height of water behind the dam. It has already accepted that erosion starts in a certain value of hydraulic gradient and depends on the cohesion of the base soil. On the other hand little studies such as Leonard et al. [1991] and Foster and Fell [1999] expressed that hydraulic gradient have also an upper limit in which no erosion occurs. This means that erosion exists in a specific range of Hydraulic Gradient which is very important in our laboratory models in which erosion should start in the first steps of test.

5.7 Internal Stability of Filter

The first job for filter is to protect its particles from erosion. It means that filter should have this primary property to be able to control the soil erosion. Kenney and Lau [1985] focused on this topic. Their study introduces another filter property called the Internal Stability that should be taken into account. It seems that instability would be occure in any kind of filters with any gradation curve either regular or irregular. Their method and other methods of checking if a filter is internally stable has been compared by Chapuis [1991].

5.8 Filter Thickness

Experts consider that an optimum thickness exists for each filter. It means that a thicker filter than the optimum cannot control more erosion. However there is no general acceptance on the method to find this thickness. Indraratna and Vafai [1997] argued that the optimum thickness depends not only on shape and type of the structure but also on hydraulic gradient. They suggest a repeating test method to find the optimum thickness.

5.9 Problematic Soils

Problematic soils should not be used in an embankment dam. Besides, ICOLD95 [1994] does not prevent this usage where no suitable soil is available. Sherard et al. [1989] did not express any different criteria and found their previous proposed criteria useful for dispersive soils. Foster and Fell [1999] suggested to be more conservative in using these criteria. Farzaneh [2000] and his students studied filters for dispersive soils. Using several tests they showed that the existing criteria are not safe and just Laboratory tests can select a suitable filter for dispersive soils.

5.10 Physico-Chemical Properties

Physico-Chemical properties of soil and water can change the filtration of a soil-filter system by reducing the permeability. The chemical reaction between free cations is the main element. These reactions can cause the sediments to settle down in the filter and reduce the conductivity of water through filter. Reddi et al. [2000] introduce this important factor. Their study was focused on low hydraulic gradient structures such as landfills, and still there is no assurance for dams.

5.11 Particle Distribution in Filter

Particle distribution causes very opposite features and properties in the filter. As it is shown in Fig 4, two different kinds of distribution in a same D_r would affect the permeability and retention functioning. There is no way other than laboratory tests to recognize these opposite cases and also cannot be introduced by simple geotechnical parameters.

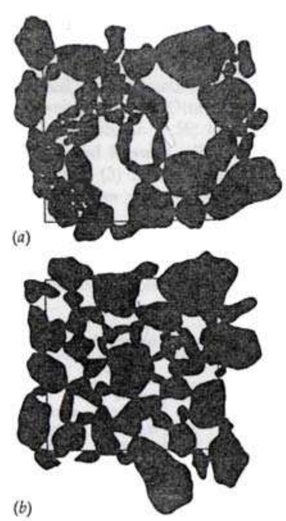

Figure 4 The effect of particle distribution in granular soils.

6 Conclusion

In this paper some of the factors affecting a soil-filter system were presented. It is clear that we cannot depend only on the criteria or any methods which do not consider all of these factors. According to this issue, it seems that the laboratory tests that can simulate the real condition including the effective factors are only and the best way to critical granular filter design.

7 Acknowledgements

Authors would like to thank Dr. Mark Foster for his kindly consultation and provision of his useful papers. Also special thanks to Prof. Indraratna and his student Mrs. Sharbaree Biswas for their helps.

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